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Micro Algae: A Carbon Capturing Third Generation Biofuel Source

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Microalgae-based biofuel is gaining wide attention among biofuel industries and researchers for its unexploited benefits. Micro algae-based biofuel is considered a third-generation renewable fuel with plenty of advantages over fossil fuels along with CO_2 mitigation. Microalgae biomass is not only a source of oil, ethanol, and biomethane but also a potential source of other high-value products. Several developed countries already have microalgae-based biofuel plants and wastewater treatment plants. India has research and development-based pilot plants at leading research institutes and research is being focused on microalgal biomass production from municipal wastewater treatment, marine water, dairy or food processing effluent and using low-cost growth media in fresh water. With the results of it, microalgae show potential as one of the major renewable and carbon capture technologies in India.

What are microalgae?

Microalgae are a diverse group of photosynthetic unicellular organisms having sizes ranging between 3 to 30 µm and different shapes. Microalgae include eukaryotic and prokaryotic cyanobacteria and are capable of growing in very different environments. It has millions of strains which can grow in any type of water and even on a moist surface having adequate nutrients, pH (7 to 9), aeration and light intensity (1000 to 8000 flux). Like terrestrial plants, microalgae use light energy to convert carbon dioxide through photosynthesis into chemical energy in the form of biomass. Microalgae reportedly have higher photosynthesis efficiency and can utilize 1.6 to 2 kg of CO_2 per kg of algal biomass during the process.

Compared to terrestrial oilseed crops, microalgae can produce 5 to 10 times biomass considering land, other resources and time requirements due to the higher growth rate and short life cycle of algae. Unlike conventional crops, microalgae are capable of growing in poor quality, salty, brackish and wastewater. Thus, algae being a non-food source has a big potential to recycle liquid waste or gaseous waste streams back to organic biomass more efficiently than conventional crops by utilizing nitrates, phosphates, and other inorganic elements. These microalgae contribute as the largest oxygen producers on the earth and can produce many high-value compounds, proteins, fine chemicals, omega-3 fatty acids, anti-oxidants and pigments which can be used in the production of pharmaceuticals, cosmetics, nutrition, fine chemicals, food and feed. Besides this oil-producing algae contain oil up to 60% of their dry mass making them potential future biofuel (Ullah, et al., 2014). This makes microalgae mitigate CO_2 and energy generation simultaneously.

Production of microalgae

Though microalgae can grow in their natural habitat as lakes, ponds, rivers, coastal streams, and backwater streams, however, for production and harvesting the biomass, they need isolated structures. There are some established popular structures used worldwide as i) Open ponds (Raceway and circular ponds), ii) closed systems called photo bioreactors. Closed systems are of different types like flat panel, tubular, spiral, etc. made up of transparent material, PVC, glass etc. and are semi-continuous types. Open pond structures are more vulnerable to contamination and environmental conditions than closed ones. In a closed structure, biomass can be produced more efficiently than open pond by using nutrient, light intensity, and temperature control. Due to a closed environment, potential contamination can be prevented. Land and water requirements can be reduced by many folds in the case of vertical installation and preventing water evaporation respectively (Joy and Anju, 2023).

For open ponds, water depth is to be maintained up to 40 cm so that light can pass through the water. Circulation or aeration of water can be assisted by paddle wheels rotating at around 40 rpm to ensure exposure of media water to the light and atmospheric CO_2. With some preventive measures, contamination can be avoided in open ponds. Closed systems are more suitable for high-value products as they produce quality biomass; however, operating costs are higher due to circulation, aeration, cooling, light intensity, pH control and maintenance than open ponds.

In India, there are wastewater treatment-based microalgae production plants, where gasifiers scrubbing water, food industrial wastewater, municipal wastewater, dairy effluents, etc. are being treated. Some of them are used to harvest biomass and used for biofuel production and others are solely for capturing

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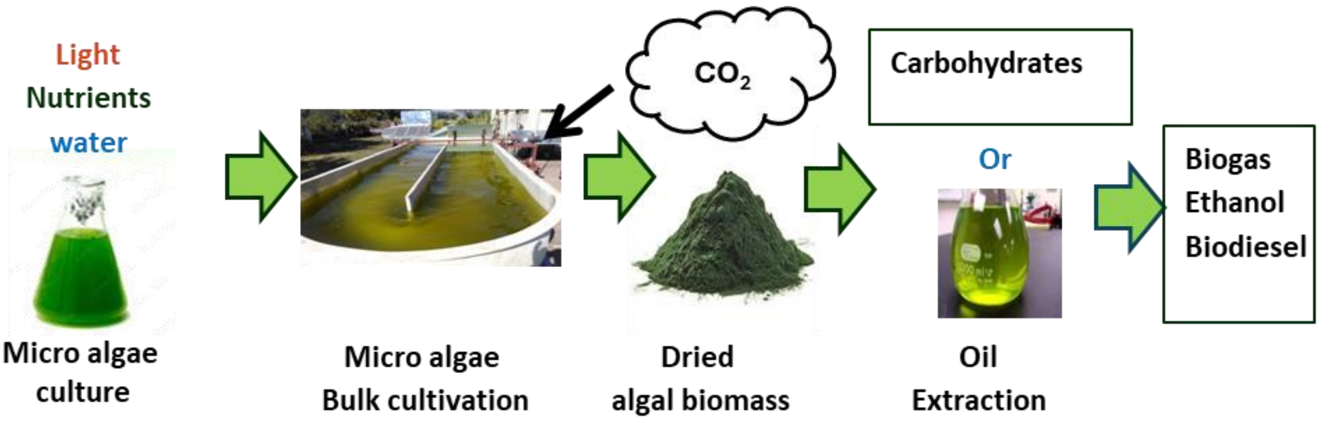

Micro algae cultivation and utilization for biofuel production

CO_2, and heavy metals to reduce greenhouse gas production and water pollution respectively. Thus, wastewater can be used for microalgae production depending on its toxicity. For optimum microalgae growth, temperature should be in the range of 15 to 30 °C, However, a dominant strain can grow at higher temperatures in the specific environment. Nutrient stress has a positive effect on lipid extraction.

Harvesting of microalgae biomass

As Microalgae grow in much-diluted form, optimum biomass production ranges between 0.9 to 1.4 g/ L in open ponds depending on the environmental conditions and for the closed system, it can be 13.7 g /L of media (Pulgarin, *et al.,* 2021). Harvesting of algal biomass is solid–liquid separation technique. As microalgae have a wide range of sizes and shapes, these techniques are effective as species-specific. These techniques include filtration, centrifugation, coagulation, floatation, and flocculation using natural; chemical; electro flocculants, and a combination of methods. The harvesting method can be selected depending on culture condition, size, shape of algae and the end product utilization. Mechanical methods like filtration and centrifugation are safer, however time and cost required make them restricted for a few applications. Care should be taken to reduce the contamination of chemicals and other materials during harvesting for quality biomass.

Biofuel production

Depending on the species and the habitat such as seawater, brackish, freshwater, and wastewater, the composition of microalgae varies in the form of carbohydrates, proteins, and lipids. Depending on the composition, the microalgal biomass can be converted into various biofuels such as crude oil, bioethanol, biodiesel, bio-jet fuel, methane, biohydrogen, etc. Microalgae consisting of carbohydrates can be used for the production of bioethanol through fermentation. The lipid-producing microalgae are used in biodiesel production by extracting the lipids followed by a transesterification process. In-situ transesterification, or the use of ionic liquid as solvent is being researched recently. Recent research also focused on the production of microalgae-based enhanced quality crude oil using different catalysts; the Hydrothermal liquefaction process is proven to be suitable for microalgal biomass. Microalgae is also focused on research as a suitable feedstock for bio-jet production and to reduce its cost of production. Microalgae as fresh or as de-oiled biomass can be used for biomethane production. However, microalgae do not have the C/N ratio required for biomethanation, it can be used as a substrate with cow dung or pig manure for energy recovery in the range of 27.4% and 81%, respectively. Microalgae also can be used to produce bio-hydrogen as per their carbohydrate content (Singh et al. 2019). Possible carbohydrate content of microalgae can be achieved by optimized process parameters and hydrogen can be generated through dark fermentation by mixed acidogenic bacteria.

Microalgae species	Biofuel	Yield (dry wt basis)
Scenedesmus sp.	Bio-ethanol	0.266 g g^{-1}
Neochloris sp.	Bio-crude oil	36%
Chlorella sp. lipids	Bio-jet fuel	76%
Chlorella pyrenoidosa	Biodiesel	80%
Mixed microalgae consortia	Bio-hydrogen	56.8 mL g^{-1}
Tetraspora sp.	Bio-hydrogen	512 mL L^{-1}
Spirulina platensis	Bio-oil	58–60%
Chlorella sorokiniana	Bio-oil	32.3%
Chlorella pyrenoidosa	Bio-methane	348 mL g^{-1} VS)

Status, Challenges, and the way forward

The main constraint in biofuel production from microalgae is the production cost which involves cost of growth media, pre-treatment of substrate used as growth media and its harvesting. There is a need to explore the oil rich microalgae strains dominant in different areas of Indian tropical and sub-tropical conditions. New ways of harvesting by hybrid cultivation of microalgae-bacteria can be further studied. The process of developing low-cost media and wastewater treatment is needed to be focused along with an enhancement of lipid content in microalgae and media recycling. To eradicate the cost of growth media, ICAR – CIAE has developed low-cost growth media based on crop residue and solar-assisted harvesting for freshwater algae *Chlorella vulgaris and Scendesmus obliquus* in open raceway pond (Jadhav *et al.,* 2021). Different treated crop residue-based substrates are adequate in nutrients and produce more biomass than standard growth media. This way, carbon capture will be doubled as it utilizes crop residue which is being burned. Many leading research institutes in India have understood the importance of microalgae and are working on different aspects of microalgae-based biofuels in the view to make it more viable for biofuel generation.

Considering the huge advantages of microalgae biomass as a biofuel source and its use for other high-value products, further research to explore cost reduction possibilities may direct the microalgae as one of the leading arenas of renewable energy for India.

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